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A CASE STUDY OF THE WINTER CIRCULATION AT 700 AND 500 MB IN MIDDLE AND HIGH SOUTHERN LATITUDES

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ABSTRACT

Synoptic chart data for the Southern Hemisphere south of 30°S (excluding the Pacific sector) are examined for the winter of 1962 in relation to the frequency of cyclones and anticyclones at the 700- and 500-mb levels. Regions of high cyclonic frequency are noted and aspects of those in the eastern Ross Sea and in Prydz Bay are discussed. Cyclonic frequency over east Antarctica is very low, but clearly defined anticyclones at 500 mb are apparent on 1 day in 6 over the highlands close to 80°S, 60°E. The longitudinal frequency of prominent troughs and ridges and some aspects of the pattern of cyclogenesis for this period are described.

1. INTRODUCTION

Few studies are available of the lower tropospheric circulation patterns for middle and high latitudes of the Southern Hemisphere (fig. 1). Until the expansion of the station network during the International Geophysical Year (IGY), the data were totally inadequate, and communication difficulties both during and since the IGY have been such that extensive postanalysis is necessary to include all the available data. Only in this way is it possible to achieve an analysis product as good as the data permit. The IGY data have recently been studied in detail by van Loon (1965, 1967) and Taljaard (1967) following an earlier analysis by Astapenko (1964) and Taljaard and van Loon (1962). A previous study using surface charts from various sources has been made by the U.S. Navy Weather Research Facility (1962), and an attempt to deduce some features of the summer circulation pattern using satellite cloud mosaic data has been reported elsewhere (Streten, 1968). The present study gives further data for the winter (June through September) of 1962 which, in relation to the availability of data, is probably fairly typical of this season in the years since 1958. During this time the total amount of data has been somewhat less than in the IGY, but such that the basic analysis capability can be maintained at a similar standard.

The data are based on the chart series produced by a team of analysts from several countries at the International Antarctic Analysis Centre (IACC) in Melbourne, Australia (Phillpot, 1964). At this time the analysis products of the Centre, which are available on microfilm, included the once-daily (00 GMT) 1000-, 700-, 500-, and 300-mb charts analyzed on a 1:20,000,000 polar stereographic base, together with extensive upper air, time cross-section data for a large number of key stations in the hemisphere. The area analyzed was that south of 30°S, but omits the major region of low network density in the South Pacific. Thus, except for the region close to the Ross Sea sector of Antarctica, the whole span of latitudes in the South Pacific from 70°W to 170°W has not been analyzed. A further region where the analyses are frequently of rather low reliability is in the forties of the central South Atlantic. The use of the 700- and 500-mb series was decided upon in this investigation, as the data at the chief synoptic hour at these levels are almost as numerous as those at the surface over the greater part of the middle and high latitude parts of the hemisphere, and are in many respects more reliable due to the elimination of unrepresentative surface observations of wind and temperature at the Antarctic coast. The basic analyses

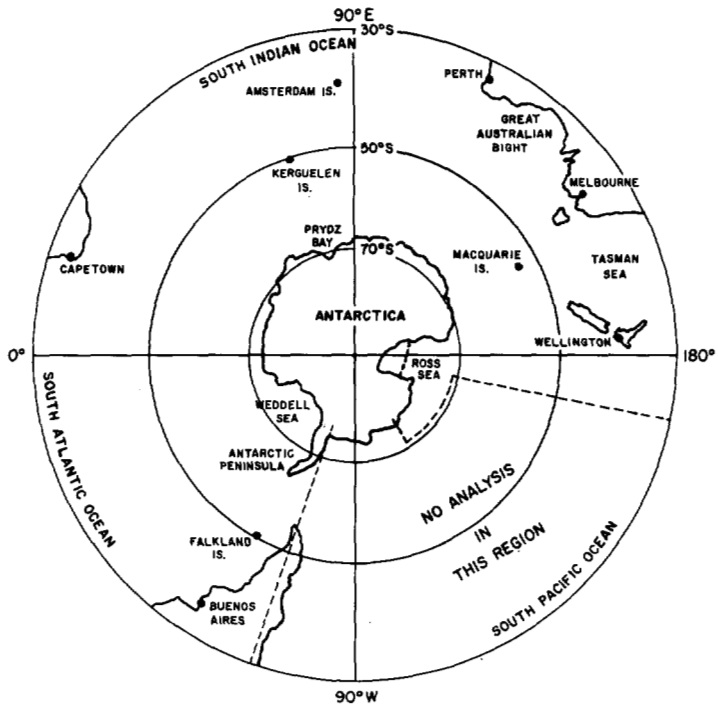

FIGURE 1.—Location map, Southern Hemisphere (polar stereographic projection).

were those at 1000 and 500 mb, the latter being constructed by thickness techniques, while the 700-mb chart was essentially a product of interpolation between the 1000- and 500-mb analyses. Vertical consistency in the analyses was thus largely maintained.

In a sparse network the danger always exists that a chart series may be drawn exhibiting high frequencies of particular pressure systems in certain areas because the analysts have a preconceived model in mind, e.g., Reed and Kunkel's (1960) appraisal of early charts for the Arctic Ocean. The geographical variation in the reliability of the IGY Charts for the Southern Hemisphere at the surface and 500-mb levels, which were produced by the South African Weather Bureau, have been discussed by Taljaard and van Loon (1964). An essentially similar degree of reliability can be inferred for the present data over the same regions. The reliability of the upper charts over continental Antarctica is not appreciably worse than that over the oceans in middle latitudes, and the identification of at least the major closed pressure systems over the continent is considered to be fairly reliable.

In order to standardize the counting of the upper air pressure systems, only Lows and Highs that were clearly bounded by at least one closed 100-m contour were included. Other systems postulated to exist on the charts, or having less clearly defined circulations as inferred from contour spacing and measured upper winds, have been excluded. They have, however, been used in the construction of cyclone tracks and in inferences of cyclogenesis. The data presented below may therefore be said to refer to well-defined pressure systems at the two chart levels.

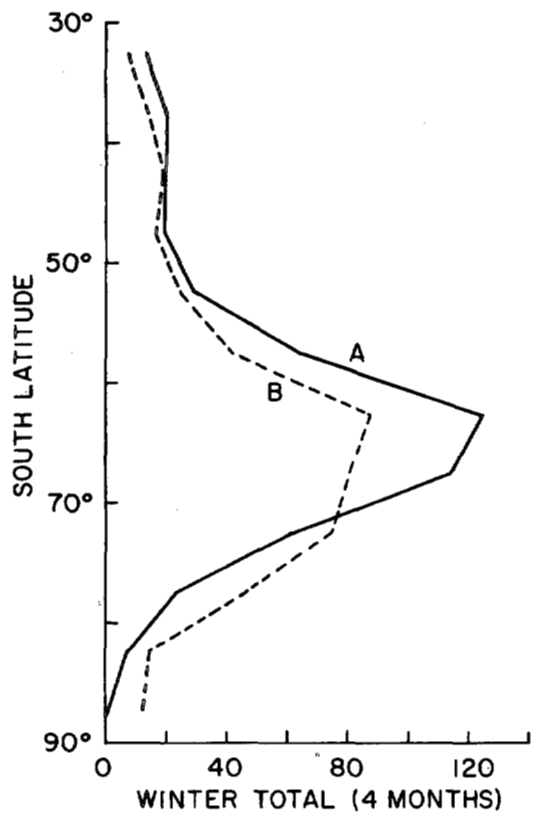

FIGURE 2.—Latitudinal variation of the frequency of cyclonic centers for the winter of 1962 in the Southern Hemisphere (70°W–00°–170°W). (A) at 700 mb; (B) at 500 mb.

2. THE CYCLONES

Figure 2 shows the latitudinal distribution of cyclones at both chart levels for the winter period. The chief features are the pronounced maxima in latitudes 60° to 65°S in the region of the Antarctic trough and the somewhat higher frequency of 500-mb Lows at latitudes south of 75°S where much of the continental ice mass rises above the mean height of the 700-mb surface. Total frequencies of cyclonic centers on a daily count at the 700- and 500-mb levels for the 4 mo are shown in figures 3 and 4. In assessing these data it was found convenient to follow the technique of Taljaard (1967). In this method the frequency is counted per unit "block" of 5° of latitude by 10° of longitude and then reduced to a standard latitude of 45° to take account of the differing areas of the unit block by multiplying by the factor $4/n$ ($\cos 45/\cos \phi$) where n is the number of months used for a season and ϕ is the midlatitude for each block. In this way the data are directly comparable with the winter data of Taljaard based on surface charts. The frequency data are then plotted together with the original plots of the centers of individual pressure systems and isopleths of frequency drawn.

A number of features are evident on the maps:

(a) The low frequencies over the high plateau of east Antarctica as opposed to the moderate frequencies over the lower region, particularly between the Weddell and Ross Seas in west Antarctica. Although, as pointed out above, 700-mb analysis is not meaningful over much of the highland area of the continent; this result appears to be a real feature at least at the 500-mb level, which is well above the highest part of the plateau. A similar belt of moderate frequency in this region is noted by Astapenko (1964) who describes analyses of data showing movement of particular Lows through this area of west Antarctica.

(b) The high-frequency belt surrounding Antarctica. Conspicuous maxima of frequency are evident at 700 mb at four locations in the trough:

(i) 0°–20°E to the north of Queen Maud Land,
(ii) 70°–80°E to the north of the Amery Ice Shelf,
(iii) 110°–120°E to the north of Budd and Sabrina coasts,
(iv) 130° to 180°W—the eastern Ross Sea and adjacent plateau of Marie Byrd Land.

Of these, (iv) is the most prominent with its highest intensity located between 75° and 80° S and 140° to 160°W. These maxima are repeated at the 500-mb level though (iii) is here less marked.

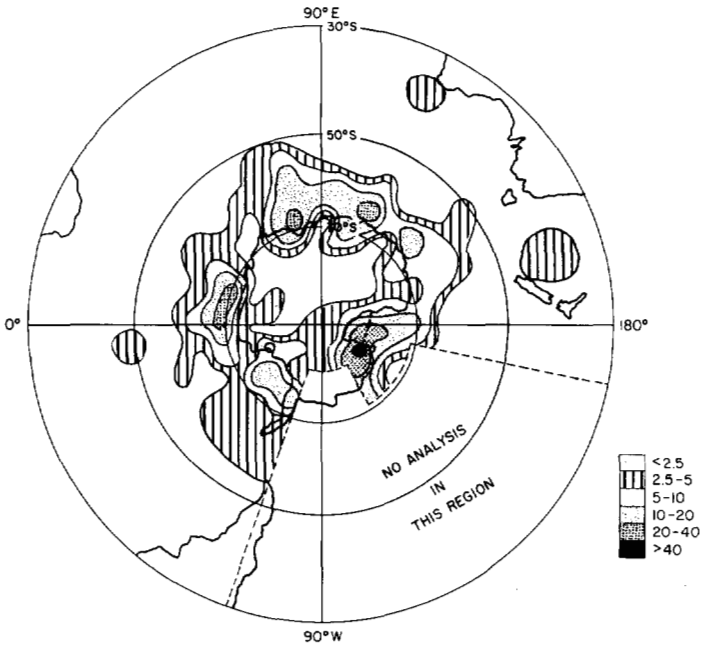

FIGURE 3.—Frequency of 700-mb cyclonic centers per "unit block" (see text) during winter of 1962.

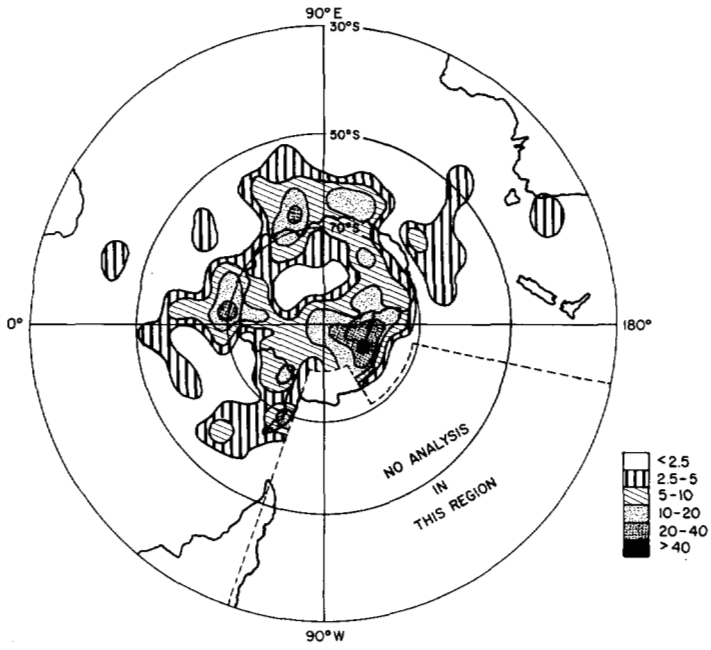

FIGURE 4.—Frequency of 500-mb cyclonic centers per "unit block" during winter of 1962.

(c) A comparatively high frequency exhibited both at 700 and 500 mb in the Tasman Sea and at 700 mb south of Western Australia.

Quantitatively the frequencies at 700 mb in high latitudes are rather similar to those of the IGY winter surface analysis of Taljaard (1967), and the most prominent maxima in the Antarctic trough are largely repeated in the same general longitudes. The eastern

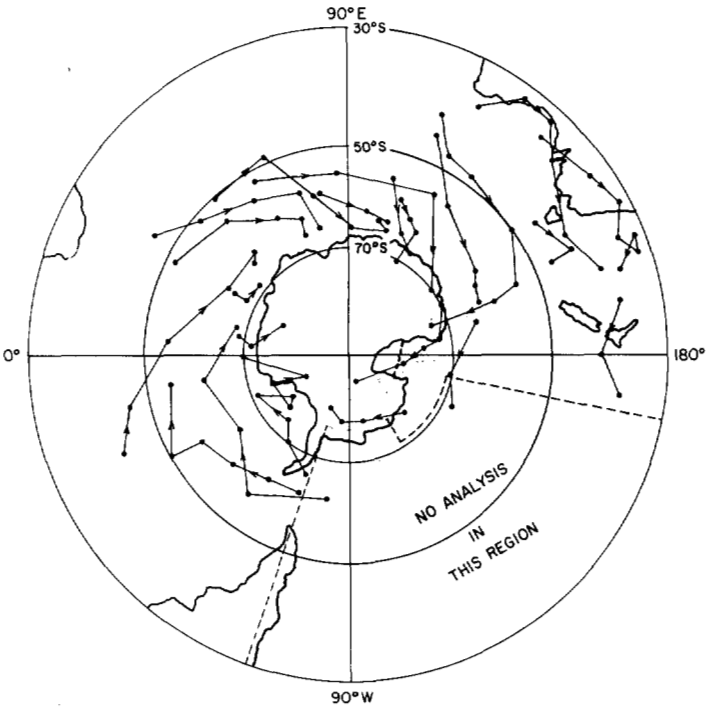

FIGURE 5.—Tracks of 700-mb minima for September 1962.

Ross Sea and adjacent plateau exhibit the highest frequencies in both the present and the IGY surface data, and this region has figured in many of the earlier studies as one of high cyclonic frequency and as a postulated "graveyard" of midlatitude cyclones. A second region that appears to be analogous to the Ross Sea in this respect is that of Prydz and Mackenzie Bays to the north of the Amery Ice Shelf.

Such very high cyclonic frequencies at particular sections of the Antarctic coast are of considerable interest, and, as pointed out by Taljaard, many of these regions coincide with the major indentations of the continental coast. The extent to which such high frequencies are a result of cyclonic movement into and stagnation in the region is doubtful. Tracks of 700- and 500-mb minima (not necessarily enclosed by a 100-m closed contour) that could be followed in the chart sequences for at least 3 days were plotted for the 4 mo. An example is given in figure 5 showing the tracks for the month of September. The construction of such tracks is rather difficult, as pointed out by Taljaard and van Loon (1962), and is subjective to some degree. Many of the tracks for this winter season are found to terminate in such regions of high cyclonic frequency as the Ross Sea and Prydz Bay. However, the consistent repetition of the low centers at such preferred locations makes it difficult to explain the high frequency as due merely to the continued movement of depressions to these areas, though this undoubtedly plays a large part. The postulate of some form of quasi-permanent low circulation appears to be necessary to

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fully explain such high cyclonic frequency in such locations as the Ross Sea.

In this regard such a system would be analogous to the Icelandic and Aleutian Lows of the Northern Hemisphere which, as Petterssen (1950) has shown, are located in minima of cyclogenesis and are maintained partly by an import of vorticity from adjacent cold sources and partly by the influx of traveling cyclones from the midlatitude belt. James (1952) has discussed theoretically the maintenance of "steady-state" circulations using dynamic and thermodynamic arguments. There are several factors which may be significant in causing the high frequency of low-pressure systems in the Ross Sea (and possibly in Prydz Bay also):

(a) Both regions are located eastward of high mountains or icecaps from which the descent to the sea level is abrupt—particularly so in the case of the Ross Sea. Such localities in the westerlies of both hemispheres experience a high frequency of cyclones and of cyclogenesis, e.g., east of the Coast Range, the Rocky Mountains, and the Appalachian Range in North America (Klein, 1957), the Andes in South America, and the Great Dividing Range in southeast Australia. Petterssen (1950) points out that many Lows so formed remain local and of short life, though others develop and travel downstream.

(b) Both regions are partially enclosed by cold landmasses and are, even in winter, often regions of open water. Petterssen has described similar situations in the Northern Hemisphere and cites such locations at Baffin Bay in both summer and winter, and the North American Great Lakes and the Gulf of Alaska in winter, as regions of high frequency of cyclones and of cyclogenesis. These regions are also clearly defined in later maps published by Klein (1957). The factor of open water in winter may be significant, and evidence exists, e.g., in a review by Heap (1964) to indicate that there exists a much greater ice concentration in the Weddell Sea than in the Ross Sea at least at the end of summer. Aerial observations by the author in the winter of 1960 and discussions with the crews of a number of aircraft of the Australian National Antarctic Research Expedition that have operated from Mawson station across Prydz Bay in winter indicate extensive open water areas on almost all occasions when the coast farther westward was blocked by fast ice for several hundred kilometers offshore. However, conclusive evidence on the prevalence of open water in the coastal indentations is difficult to obtain and rapid changes in sea-ice distribution over a wide area have been observed (e.g., in the satellite observations of September 1964 made by Knapp, 1967). Moreover, the existence of open water is not, of course, independent of the lower atmospheric circulation.

The explanation of the very high cyclonic frequencies in the eastern Ross Sea that have been observed in a number of studies may, however, be partly related to the location to the east of the high mountains and plateau of Victoria Land and in a region where open water could act as a heat source for a quasi-permanent local circulation. To a lesser degree, similar factors may be involved in the case of the Mackenzie Bay-Prydz Bay region. The otherwise analogous Weddell Sea may experience lower frequencies of cyclonic activity due to the inhibition of any local circulation by the high ice concentration and also (perhaps, primarily) because the general pattern of cyclonic tracks that have been published by various authors appears to be directed farther to the west of the coastal indentation. The higher frequency regions located on the coast of east Antarctica, which appear both in the present and Taljaard's data (1967), must be assumed to be related to considerable general regularity in the tracks of cyclones moving from lower latitudes toward the coast of the continent. In the present data it is noticeable that the maxima at 0° to 20°E and at 110° to 120°E are more pronounced at the 700-mb level than at 500 mb, while those in the Ross Sea and Prydz Bay are equally marked at both levels. This is suggestive that while the two secondary maxima may be related to decaying cyclones, the two maxima in the coastal indentations may be connected with some form of more permanent circulation. However, many more long-term analyses of chart data are required before any conclusive statements can be made on the nature of the cyclonic frequency maxima surrounding Antarctica.

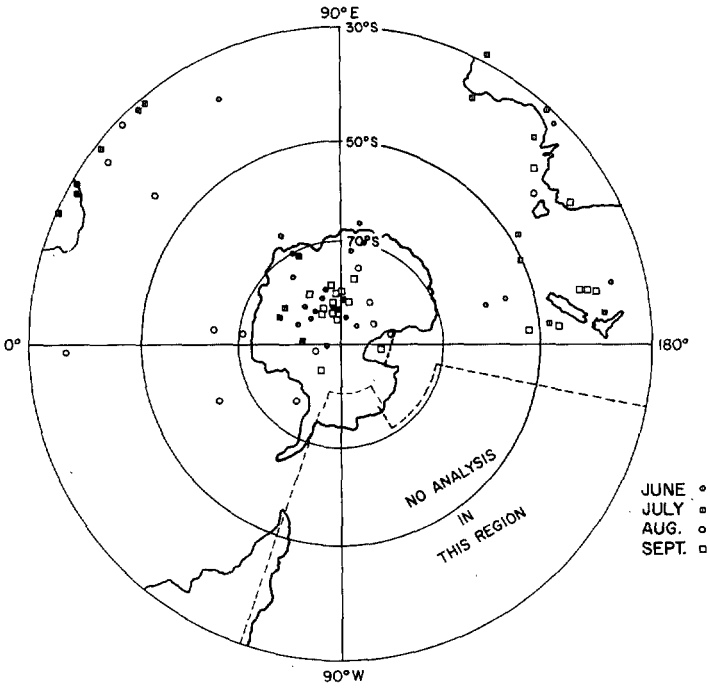

FIGURE 6.—Location of individual anticyclonic centers at 700 mb during winter of 1962.

3. THE ANTICYCLONES AND MERIDIONAL RIDGES

Figures 6 and 7 show the locations of individual anticyclonic centers at both chart levels for the 4 winter mo. The southern part of the subtropical maximum of anti-

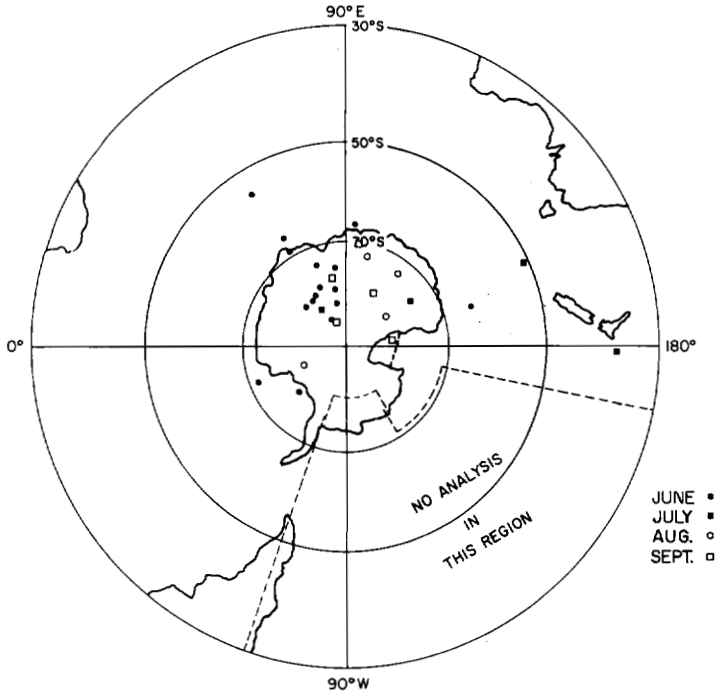

FIGURE 7.—Location of individual anticyclonic centers at 500 mb during winter of 1962.

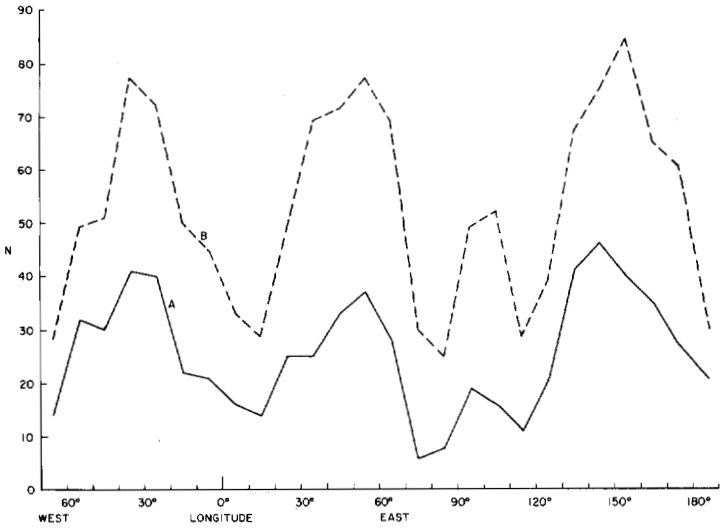

FIGURE 8.—Total number of well-defined ridges at 700 mb (N) per 10° long. block; (A) lat. 55°–75°S; (B) lat. 30°–90°S.

cyclones close to lat. 30°S is apparent at the fringe of the analysis area but appears only at the 700-mb level. The well-known almost total absence of closed anticyclonic circulations in the higher middle latitudes (Lamb, 1959) is the most prominent feature. The sole region at these latitudes that shows any number of anticyclones is that near to, and south of, the Tasman Sea and New Zealand, though a few centers are apparent in the southern South Atlantic. Centers at 500 mb over the high latitude ocean area are rare.

As explained above, the higher frequencies over continental Antarctica, at least at 500 mb, are thought to be real due to the restriction imposed on the counting of the systems. The plots of anticyclones tend to be clustered close to 80°S, 60°E, near the highest part of the east Antarctic Plateau. It is near this longitude (corresponding to the coast east of the Enderby Land peninsula) that the few high latitude anticyclones at sea level are located.

On the average, a well-defined 500-mb anticyclone could be detected over the east Antarctic Plateau on about 1 day in 6 during the 4-mo period. At 700 mb, the equivalent frequency was 1 day in 4. The frequency of cyclones here was very low and for the greater portion of the time weak anticyclones or col situations prevailed.

Despite the lack of closed anticyclones over the high southern latitude ocean areas, pronounced meridional ridge lines are frequent, and an attempt has been made to determine relative frequencies at particular longitudes over the analysis area. In doing this it was found convenient to take the coast of Antarctica as a reference. The axis of regions of high geopotential at the coast were identified and the ridge line extended meridionally as far as was consistent with the analysis data. Well-defined regions with geopotential considerably higher than at adjacent parts of the coastline are readily observed at the Antarctic coast. Such high-pressure regions are frequently associated with westerly winds where a midlatitude ridge extends as far south as the coast interrupting the Antarctic trough, though at other times the high geopotential values are observed with easterly winds and associated with extensions of higher pressure from the interior of the Continent. More often, however, such ridges with easterly winds at the coast are coincident in time with corresponding ridges extending southward from midlatitudes at the same meridian. Only sharply defined ridges were counted, broad areas of westerly flow at rather high geopotential values at the coast being excluded. The frequencies were calculated per "unit block" and the variation with longitude over two ranges of latitude are shown in figure 8, for the available range of longitude at the 700-mb level. Prominent high frequencies occur at 30°–40°W, 50°–60°E, and at 140°–160°E, with a lesser maximum at 100°–110°E. This pattern is essentially reflected in the 500-mb data, though at this level the maxima at 100°–110°E is much more prominent. The longitudes of ridge maxima are consistent with the cyclonic frequencies of figures 3 and 4, the high cyclonic frequency at longitude 70°–80°E being particularly well defined. It is hoped that further analysis of longer chart series will enable data similar to that published by Klein and Winston (1958) for the Northern Hemisphere to be obtained.

The longitudes to the east of the regions of maximum ridge frequency may be inferred to be locations of most frequent initial outbreak to lower latitudes of sub-

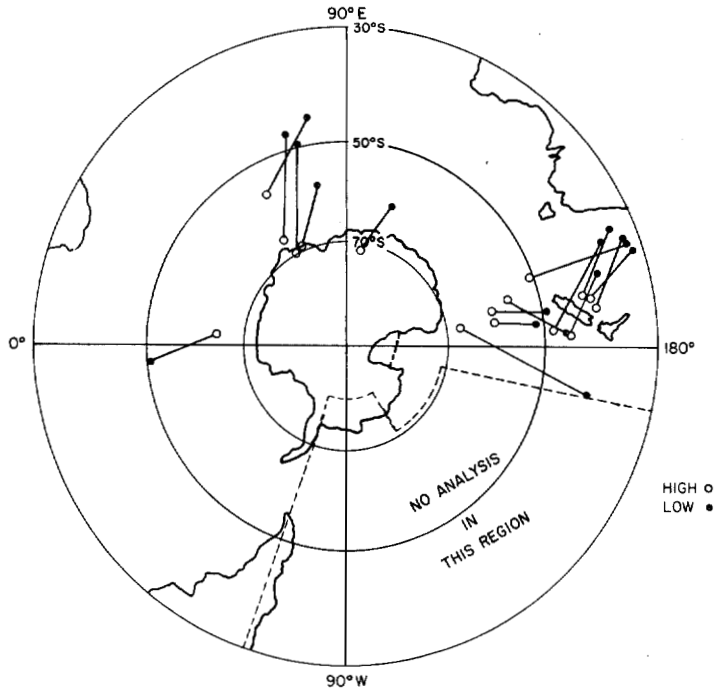

FIGURE 9.—Location of individual blocking patterns at 700 mb during winter of 1962.

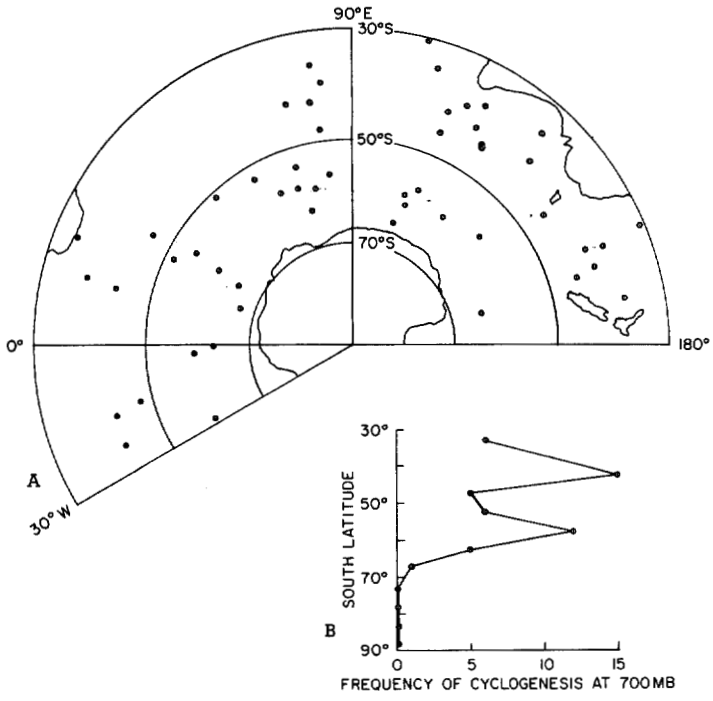

FIGURE 10.—(A) location of individual origin points of 700-mb minima and (B) latitudinal variation of origin points at 700 mb during winter of 1962.

Antarctic air during the winter period. Studies such as those of Treloar (1960) and Hannay (1960) have indicated that cold outbreaks affecting southeast Australia frequently originate as a cold air stream as far east as 70°–80°E in latitudes around 55°S, and Lamb (1959) has compared the considerable glaciation of Heard Island (53°S, 74°E) and Kergulen Island (44°S, 70°E) with the completely ice-free conditions of Macquarie Island (55°S, 159°E). The present data tend to support the concept of frequent outflow to the north at a longitude corresponding to the east of the Enderby Land peninsula on the Antarctic coast.

4. BLOCKING SITUATIONS

Upper air patterns characteristic of blocking situations, though rare, are readily recognizable in the chart sequences on a number of occasions during the winter. The location of the individual patterns is shown in figure 9 for the 700-mb level. The Tasman Sea and the region south and southeast of New Zealand, which are well known to analysts in this region as the location of most frequent blocking, are the most prominent sites during this period of study. A secondary region with less frequent occurrences is located north of Enderby Land in long. 50°–60°E. The blocking region in the Scotia Sea in the southwest Atlantic that has been noted by van Loon (1956) was not observed in this winter series, though this could possibly be due to the doubtful nature of the charts in this region.

5. SOME FEATURES OF THE CYCLOGENESIS PATTERN

In the preparation of the maps showing the tracks of cyclone movement, an attempt was made to locate positions of cyclogenesis. The data for the 700-mb level were used, and the location, at which a closed circulation (not necessarily enclosed by a 100-m contour) was first apparent, was taken as the point of cyclogenesis. The origin of the Lows moving through the area near the western part of the analysis area is frequently indeterminate, and for this reason only the region from 30°W eastward to 180° was considered. By retracing tracks that were reasonably clearly defined for at least 3 days, it was usually possible to locate the origin of the 700-mb circulation with some degree of confidence.

The result of the analysis is shown in figure 10. It will be noted that there is a considerable spread of the points over most of the ocean area similar to that shown in the winter chart of Taljaard (1967). Although the data are barely sufficient to indicate a clear division, there is, particularly south of Australia, a suggestion of two bands, one at 40° to 45°S and the other at 55° to 60°S. If such a division does exist, it would not be inconsistent with the data of double-winter wind maxima in the high troposphere of the Southern Hemisphere as indicated in the study of Phillpot (1962) or with the long-term distribution

of average zonal wind in July as shown by van Loon (1964). The data on cyclogenesis given by the latter author (1965) based on the IGY surface charts for the whole hemisphere show, however, no such double-winter maximum in middle and high latitudes, and further data will be necessary to determine if any such banding in the frequency of winter cyclogenesis is real.

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